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(54) **EXHAUST SYSTEM COMPONENT INPUT PRESSURE ESTIMATION SYSTEMS AND METHODS**

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| ***F02B 37/22*** | (2006.01) |
| ***F02M 25/07*** | (2006.01) |

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CPC ... F02B 37/22; F02D 41/008; F02D 41/0052; F02D 41/14; F02D 41/1444; F02D 41/1445; F02D 41/1446; F02D 41/1447; F02D 41/1448; F02D 41/145; F02D 2041/1423; F02D 2041/1433

USPC .......... 701/103–106, 109–110; 123/672, 673, 123/674, 676, 679, 703; 60/274, 285, 286; 73/114.69, 114.71, 114.72, 114.73

See application file for complete search history.

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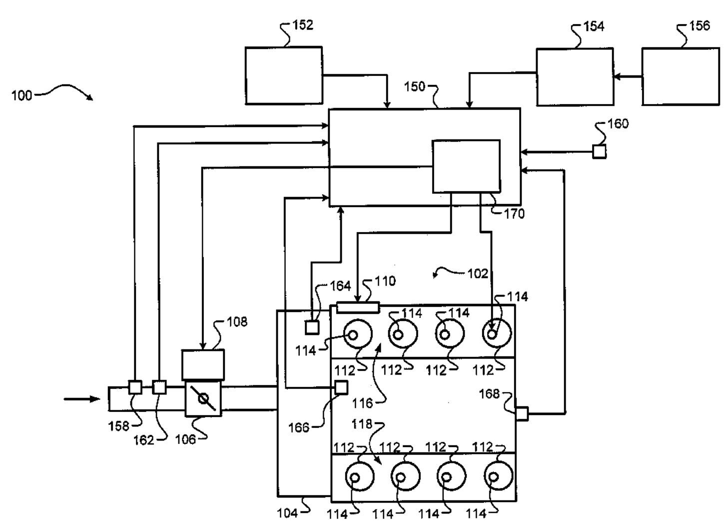
(57) **ABSTRACT**

An output pressure module that sets an output pressure of a first component of an exhaust system of the vehicle equal to one of: an input pressure of a second component that is immediately downstream of the first component in the exhaust system; and ambient air pressure. A pressure drop module determines a pressure drop between an input of the first component and an output of the first component based a temperature of exhaust input to the first component. An input pressure module determines an input pressure of the first component based on a sum of the output pressure of the first component and the pressure drop between the input and the output of the first component. An actuator control module selectively controls at least one engine actuator based on at least one of the input and output pressures of the first component.

**20 Claims, 5 Drawing Sheets**



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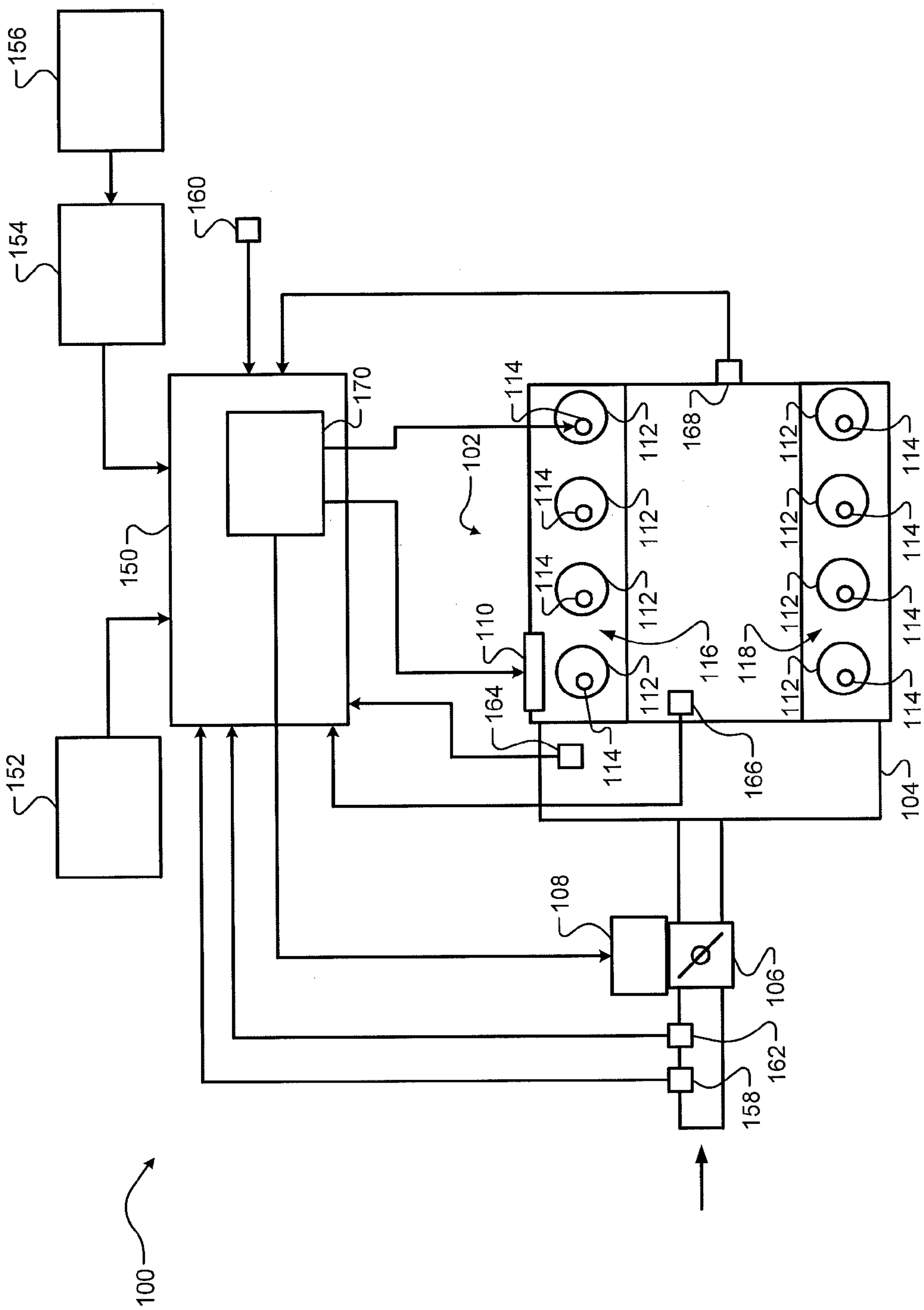
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FIG. 1

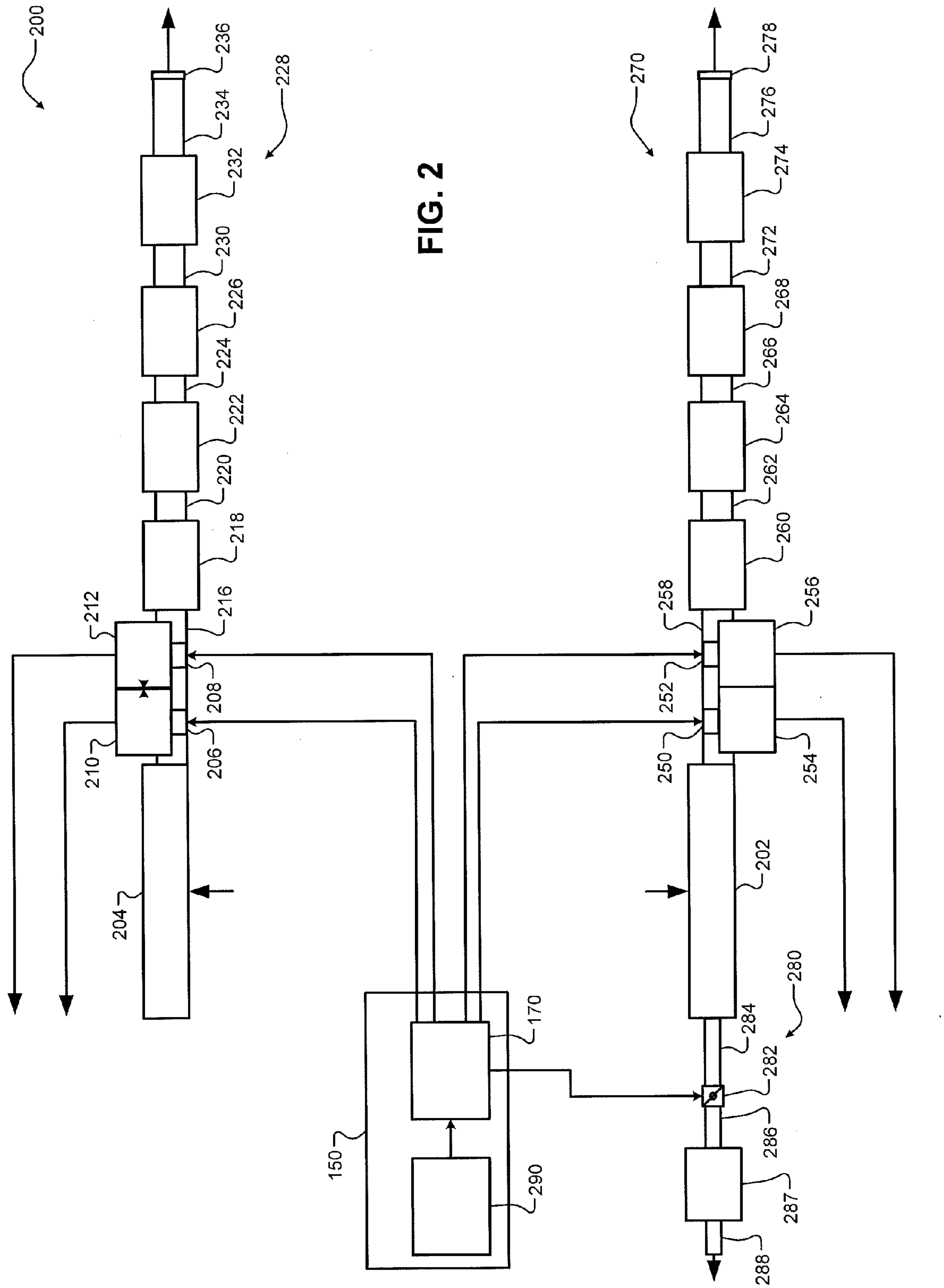
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FIG. 2

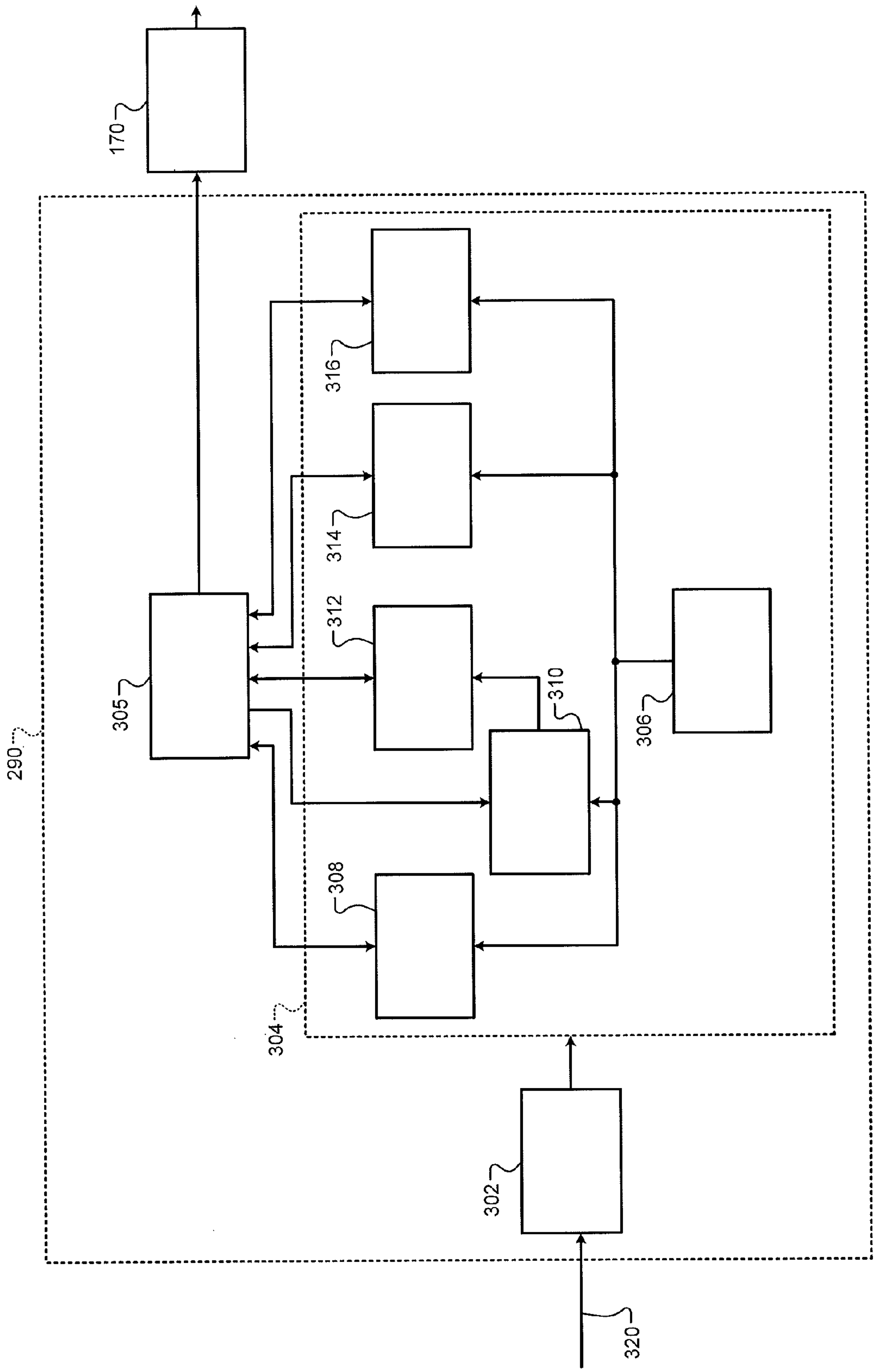


FIG. 3

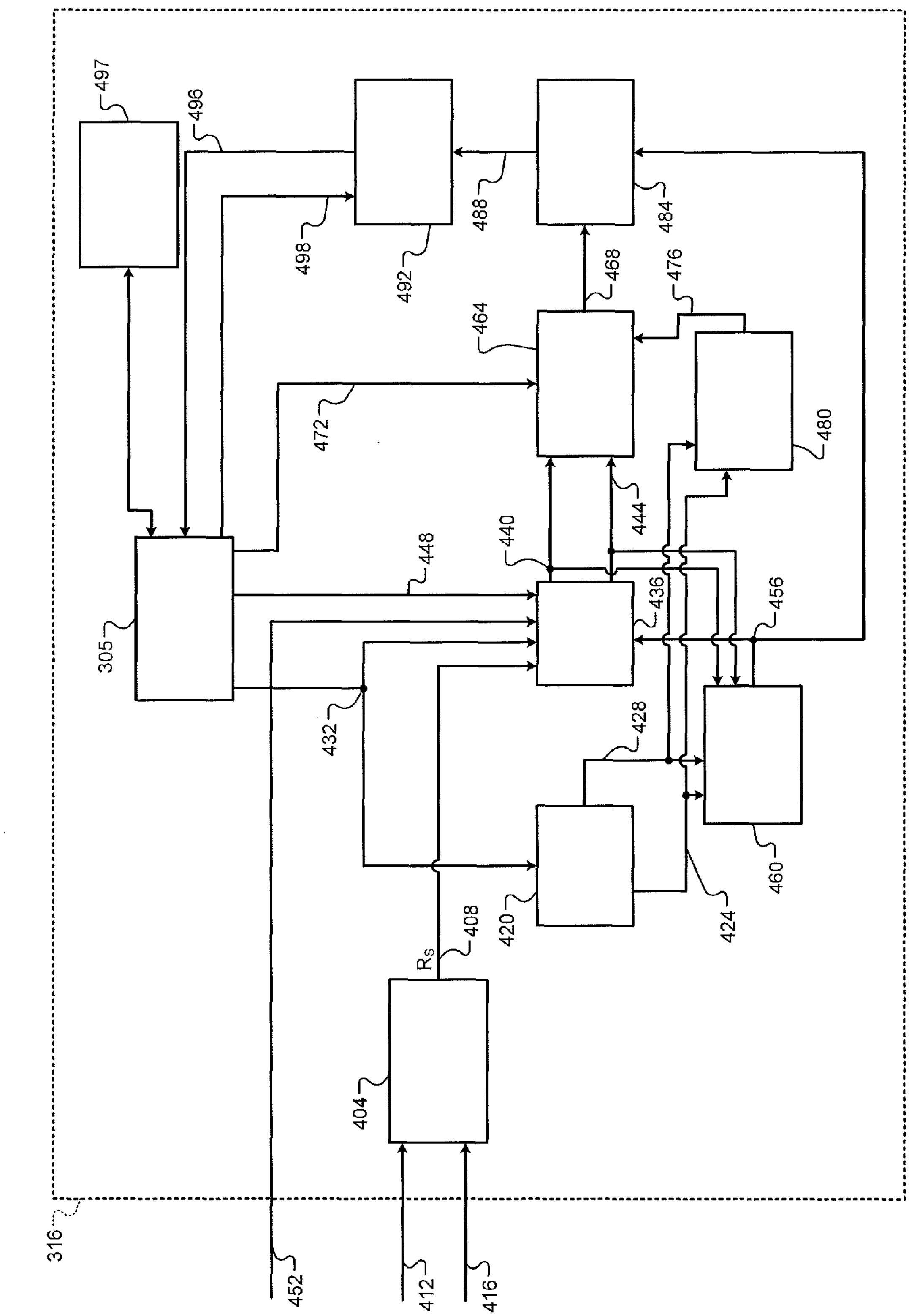

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FIG. 4

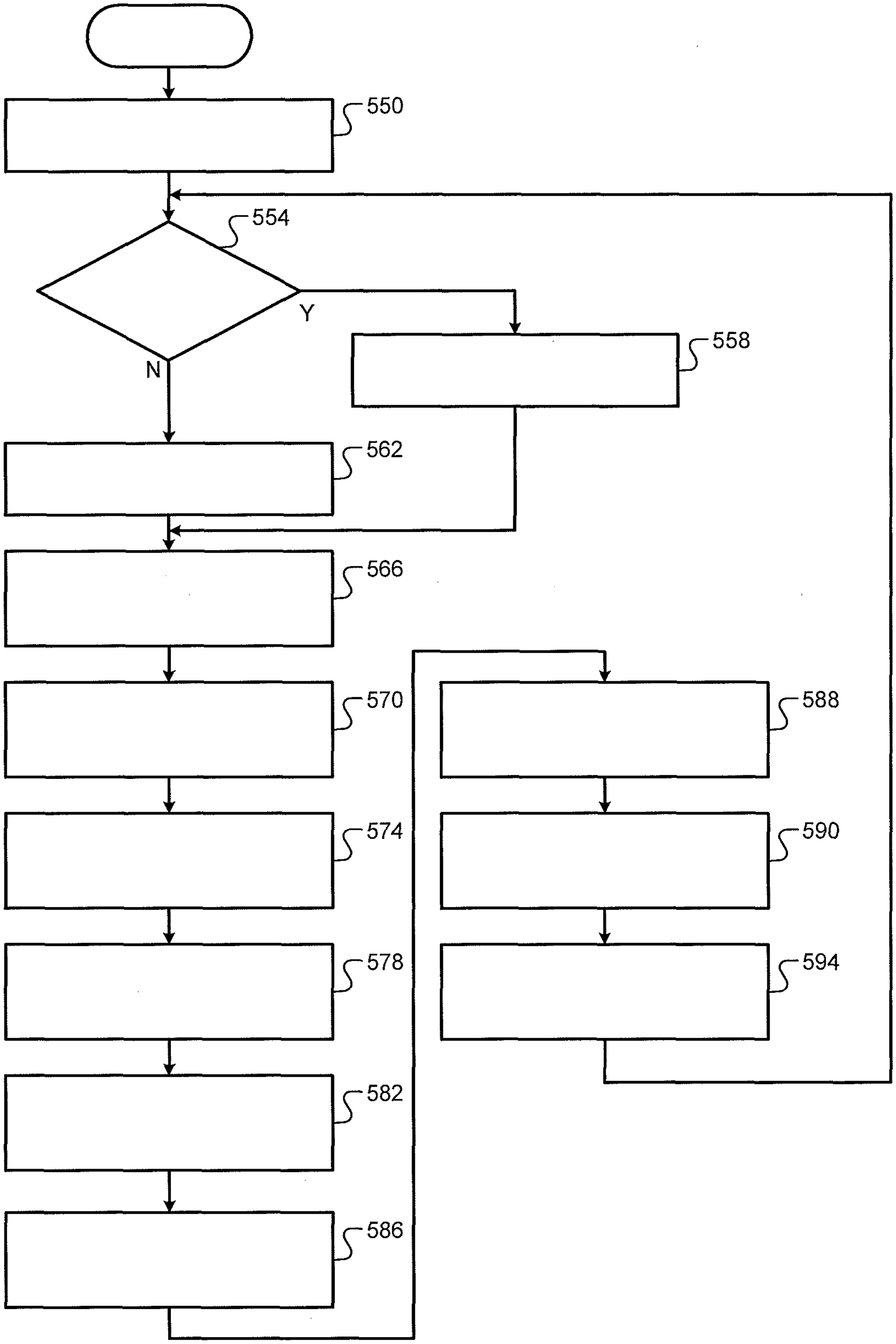


FIG. 5

# EXHAUST SYSTEM COMPONENT INPUT PRESSURE ESTIMATION SYSTEMS AND METHODS

## FIELD

The present disclosure relates to internal combustion engine systems and more particularly to exhaust systems.

## BACKGROUND

The background description provided here is for the purpose of generally presenting the context of the disclosure. Work of the presently named inventors, to the extent it is described in this background section, as well as aspects of the description that may not otherwise qualify as prior art at the time of filing, are neither expressly nor impliedly admitted as prior art against the present disclosure.

An engine combusts a mixture of air and fuel to produce drive torque and propel a vehicle. Air is drawn into the engine through a throttle valve. Fuel provided by one or more fuel injectors mixes with the air to form the air/fuel mixture. The air/fuel mixture is combusted within one or more cylinders to produce drive torque. An engine control module (ECM) controls the torque output of the engine.

Exhaust gas resulting from combustion of the air/fuel mixture is expelled from the engine to an exhaust system. The ECM may adjust one or more engine parameters based on signals from various sensors that are located in the exhaust system. For example only, one or more temperature sensors and/or exhaust flow rate sensors may be located in the exhaust system. The ECM may adjust, for example, airflow into the engine, the amount of fuel injected, and/or spark timing based on the signals.

The sensors provide the ECM with measurements regarding conditions within the exhaust system and allow the ECM to adjust one or more engine parameters to create desired exhaust conditions. As the number of sensors implemented in the exhaust system increases, however, the cost of producing the vehicle also increases. The increased production cost may be attributable to, for example, the sensors themselves, associated wiring and hardware, and/or research and development. Additionally, a vehicle producer may produce a variety of different vehicles, and each of the different vehicles may have a different exhaust system. Calibrating and adjusting sensors implemented in each different vehicle and exhaust system may also increase vehicle production cost.

## SUMMARY

In a feature, an output pressure module that sets an output pressure of a first component of an exhaust system of the vehicle equal to one of: an input pressure of a second component that is immediately downstream of the first component in the exhaust system; and ambient air pressure. A pressure drop module determines a pressure drop between an input of the first component and an output of the first component based a temperature of exhaust input to the first component. An input pressure module determines an input pressure of the first component based on a sum of the output pressure of the first component and the pressure drop between the input and the output of the first component. An actuator control module selectively controls at least one engine actuator based on at least one of the input and output pressures of the first component.

In further features: the output pressure module further sets an output pressure of a third component of the exhaust system that is immediately upstream of the first component in the exhaust system equal to the input pressure of the first component; the pressure drop module further determines a pressure drop between an input of the third component and an output of the third component based a temperature of exhaust input to the third component; and the input pressure module further determines an input pressure of the third component based on a sum of the output pressure of the third component and the pressure drop between the input and the output of the third component.

In further features: a viscosity module determines a viscosity of the exhaust input to the first component based on the temperature of the exhaust input to the first component; and a density module determines a density of the exhaust input to the first component based on the temperature of the exhaust input to the first component. The pressure drop module determines the pressure drop between the input and the output of the first component based on the viscosity and the density of the exhaust input to the first component.

In further features: an exhaust gas flowrate (EGF) determination module determines an EGF through the first component; and an EGF normalization module determines a normalized EGF through the first component based on the EGF and the viscosity of the exhaust input to the first component. The pressure drop module determines the pressure drop between the input and the output of the first component based on the normalized EGF.

In further features: a first normalization value module determines a first normalization value for the first component based on the viscosity of the exhaust input to the first component and the density of the exhaust input to the first component. The pressure drop module further determines a normalized pressure drop between the input and the output of the first component based on the normalized EGF through the first component and determines the pressure drop between the input and the output of the first component based on the normalized pressure drop and the first normalization value.

In further features, the pressure drop module determines the pressure drop between the input and the output of the first component based on the normalized pressure drop divided by the first normalization value.

In further features, the first normalization value module determines the first normalization value for the first component based on the viscosity of the exhaust input to the first component, a normalized viscosity of the exhaust input to the first component, the density of the exhaust input to the first component, and a normalized density of the exhaust input to the first component.

In further features, the density module determines the density of the exhaust input to the first component further based on a normalized input pressure for the first component and determines the normalized input pressure for the first component based on a normalized ambient air pressure, a previous value of the input pressure of the first component, an ambient air pressure, and the first normalization value.

In further features: a second normalization value module determines a second normalization value for the first component based on the viscosity of the exhaust input to the first component. The EGF normalization module determines the normalized EGF through the first component based on the EGF through the first component and the second normalization value.

In further features, the second normalization value module determines the second normalization value for the first component based on the viscosity of the exhaust input to the first component and a normalized viscosity of the exhaust input to the first component.

In a feature, a method includes setting an output pressure of a first component of an exhaust system of the vehicle equal to one of: an input pressure of a second component that is immediately downstream of the first component in the exhaust system; and ambient air pressure. The method further includes: determining a pressure drop between an input of the first component and an output of the first component based a temperature of exhaust input to the first component; determining an input pressure of the first component based on a sum of the output pressure of the first component and the pressure drop between the input and the output of the first component; and selectively controlling at least one engine actuator based on at least one of the input and output pressures of the first component.

In further features, the method further includes: setting an output pressure of a third component of the exhaust system that is immediately upstream of the first component in the exhaust system equal to the input pressure of the first component; determining a pressure drop between an input of the third component and an output of the third component based a temperature of exhaust input to the third component; and determining an input pressure of the third component based on a sum of the output pressure of the third component and the pressure drop between the input and the output of the third component.

In further features, the method further includes: determining a viscosity of the exhaust input to the first component based on the temperature of the exhaust input to the first component; determining a density of the exhaust input to the first component based on the temperature of the exhaust input to the first component; and determining the pressure drop between the input and the output of the first component based on the viscosity and the density of the exhaust input to the first component.

In further features, the method further includes: determining an exhaust gas flowrate (EGF) through the first component; determining a normalized EGF through the first component based on the EGF and the viscosity of the exhaust input to the first component; and determining the pressure drop between the input and the output of the first component based on the normalized EGF.

In further features, the method further includes: determining a first normalization value for the first component based on the viscosity of the exhaust input to the first component and the density of the exhaust input to the first component; determining a normalized pressure drop between the input and the output of the first component based on the normalized EGF through the first component; and determining the pressure drop between the input and the output of the first component based on the normalized pressure drop and the first normalization value.

In further features, the method further includes: determining the pressure drop between the input and the output of the first component based on the normalized pressure drop divided by the first normalization value.

In further features, the method further includes: determining the first normalization value for the first component based on the viscosity of the exhaust input to the first component, a normalized viscosity of the exhaust input to the first component, the density of the exhaust input to the first component, and a normalized density of the exhaust input to the first component.

In further features, the method further includes: determining the density of the exhaust input to the first component further based on a normalized input pressure for the first component; and determining the normalized input pressure for the first component based on a normalized ambient air pressure, a previous value of the input pressure of the first component, an ambient air pressure, and the first normalization value.

In further features, the method further includes: determining a second normalization value for the first component based on the viscosity of the exhaust input to the first component; and determining the normalized EGF through the first component based on the EGF through the first component and the second normalization value.

In further features, the method further includes: determining the second normalization value for the first component based on the viscosity of the exhaust input to the first component and a normalized viscosity of the exhaust input to the first component.

Further areas of applicability of the present disclosure will become apparent from the detailed description, the claims and the drawings. The detailed description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the disclosure.

## BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure will become more fully understood from the detailed description and the accompanying drawings, wherein:

FIG. **1** is a functional block diagram of an example engine system according to the present disclosure;

FIG. **2** is a functional block diagram of an example exhaust system according to the present disclosure;

FIG. **3** is a functional block diagram of an example exhaust system module according to the present disclosure;

FIG. **4** is a functional block diagram of an example pressure determination module according to the present disclosure; and

FIG. **5** is a flowchart depicting an example method of determining pressure at an input of a component of an exhaust system according to the present disclosure.

In the drawings, reference numbers may be reused to identify similar and/or identical elements.

## DETAILED DESCRIPTION

An exhaust system of a vehicle includes various components, such as pipes, one or more catalysts, and one or more mufflers. Some exhaust systems include one or more turbochargers and other types of components. Exhaust output by an engine flows through the components before the exhaust is expelled from the vehicle.

An exhaust system modeling module according to the present disclosure estimates input gas temperature, output gas temperature, mass temperature, input pressure, and output pressure for one or more of the exhaust system components through which the exhaust flows. The input and output gas temperatures of an exhaust system component correspond to temperatures of exhaust gas entering and exiting the component, respectively. The mass temperature of an exhaust system component corresponds to the temperature of the material that makes up the component.

The input and output pressures of an exhaust system component correspond to pressures at an input and an output of the exhaust system component, respectively. The exhaust system modeling module determines the input pressure of an exhaust system component based on an estimated pressure drop across the component and the output pressure of that component. The exhaust system modeling module estimates the pressure drop across the component based on a temperature of the exhaust input to the component. This may increase the accuracy of the estimated pressure drop and, therefore, increase the accuracy of the estimated input pressure.

Referring now to FIG. **1**, a functional block diagram of an example engine system **100** is presented. An air/fuel mixture is combusted within an engine **102** to produce drive torque for a vehicle. The engine **102** may be a gasoline-type engine, a diesel-type engine, a hybrid-type engine, and/or another suitable type of engine. The engine **102** may be configured in any suitable cylinder configuration. For example only, the engine **102** may be configured in a V-type configuration, a flat-type configuration, or an inline-type configuration.

Air is drawn into the engine **102** through an intake manifold **104** and a throttle valve **106**. The throttle valve **106** is actuated to control airflow into the engine **102**. An electronic throttle controller (ETC) **108** controls the throttle valve **106** and, therefore, airflow into the engine **102**.

A fuel system **110** injects fuel that mixes with the air to form the air/fuel mixture. The fuel system **110** may inject the fuel at any suitable location. For example only, the fuel system **110** may provide fuel into the intake manifold **104**, into intake valves (not shown) associated with cylinders **112** of the engine **102**, and/or directly into each of the cylinders **112**. In various implementations, the fuel system **110** includes one fuel injector (not shown) for each of the cylinders **112**.

The air/fuel mixture is combusted within the cylinders **112** of the engine **102**. Combustion of the air/fuel mixture may be initiated by, for example, spark provided by spark plugs **114**. In some engine systems, such as the engine system **100**, one spark plug may be provided for each of the cylinders **112**. In other engine systems, such as diesel-type engine systems, combustion may be accomplished without the spark plugs **114**. Combustion of the air/fuel mixture generates drive torque and rotatably drives a crankshaft (not shown).

The engine **102** may include eight cylinders as shown in FIG. **1**, although the engine **102** may include a greater or fewer number of cylinders. The cylinders **112** of the engine **102** are depicted as being arranged in two cylinder banks: a left cylinder bank **116** and a right cylinder bank **118**. While the engine **102** is shown as including the left and right cylinder banks **116** and **118**, the engine **102** may include one or more than two cylinder banks. For example only, inline-type engines may be considered to have cylinders arranged in one cylinder bank.

An engine control module (ECM) **150** controls the torque output of the engine **102**. The ECM **150** may control the torque output of the engine **102** based on driver inputs provided by a driver input module **152**. For example only, the driver inputs may include an accelerator pedal position, a brake pedal position, cruise control systems inputs, and other types of driver inputs.

The ECM **150** may also communicate with a hybrid control module **154** to coordinate operation of the engine **102** and one or more electric motors, such as electric motor (EM) **156**. The EM **156** may also function as a generator, and may be used to selectively produce electrical energy for use by vehicle electrical systems and/or for storage in a battery.

The ECM **150** makes control decisions based on parameters measured by various sensors. For example, intake air temperature may be measured using an intake air temperature (IAT) sensor **158**. Ambient air temperature may be measured using an ambient temperature sensor **160**. Mass flow rate of air into the engine **102** may be measured using a mass airflow (MAF) sensor **162**. Pressure within the intake manifold **104** may be measured using a manifold absolute pressure (MAP) sensor **164**. In various implementations, engine vacuum may be measured, where engine vacuum is determined based on the difference between ambient air pressure and the pressure within the intake manifold **104**.

Coolant temperature may be measured using a coolant temperature sensor **166**. The coolant temperature sensor **166** may be located within the engine **102** or at other locations where the coolant is circulated, such as a radiator (not shown). Engine speed may be measured using an engine speed sensor **168**. For example only, the engine speed may be measured based on the rotational speed of the crankshaft.

The ECM **150** may include an actuator control module **170** that controls engine operating parameters. For example only, the actuator control module **170** may adjust throttle opening, amount or timing of fuel injection, spark timing, cylinder deactivation, and/or turbocharger boost. The actuator control module **170** may also control other engine parameters, such as exhaust gas recirculation (EGR) valve opening, and/or opening/closing of intake and exhaust valves (not shown) associated with the cylinders **112** of the engine **102**.

Referring now to FIG. **2**, a functional block diagram of an example exhaust system **200** is presented. The exhaust system **200** of FIG. **2** is a generic exhaust system including exhaust system components which may or may not be included in different models and types of vehicles manufactured by a vehicle manufacturer. The exhaust system **200** includes exhaust system components through which exhaust gas flows. While the exhaust system **200** will be described, the present disclosure is applicable to other exhaust system configurations, which may include a fewer or greater number components than the exhaust system **200**. Numeric labels given to similar components of the exhaust system **200** are for distinction only, and are not representative of the relative importance of the components.

Exhaust gas resulting from combustion of the air/fuel mixture is expelled from the engine **102** to the exhaust system **200**. More specifically, exhaust is expelled from the cylinders **112** of the right cylinder bank **118** to a right exhaust manifold **202**. Exhaust is expelled from the cylinders **112** of the left cylinder bank **116** to a left exhaust manifold **204**. With respect to the left exhaust manifold **204**, the exhaust flows from the left exhaust manifold **204** past a first wastegate **206** and a second wastegate **208**. The first and second wastegates **206** and **208** are associated with first and second turbochargers **210** and **212**, respectively.

The turbochargers **210** and **212** each provide pressurized air to the intake manifold **104**. The turbochargers **210** and **212** draw in air, pressurize the air, and provide the pressurized air to the intake manifold **104**. The turbochargers **210** and **212** may draw in air from the intake manifold **104**, ambient air, and/or another suitable source. One or more of the turbochargers **210** and **212** may be, for example only, variable geometry turbochargers.

One or more intercoolers (not shown) may also be implemented to dissipate heat from the pressurized air supplied to the intake manifold **104**. The temperature of the pressurized air may be increased by, for example, the pressurization of the air and/or proximity to the exhaust system **200**.

The turbochargers **210** and **212** are powered by the exhaust gas expelled from the cylinders **112** of the left cylinder bank **116**. The wastegates **206** and **208** may allow the exhaust gas to bypass the turbochargers **210** and **212**, respectively. In this manner, the wastegates **206** and **208** may be used to reduce the output (i.e., boost) of the turbochargers **210** and **212**, respectively.

The ECM **150** controls the output of the turbochargers **210** and **212**. For example only, the actuator control module **170** may modulate the output of the turbochargers **210** and **212** by controlling the positions of the wastegates **206** and **208**, respectively. The actuator control module **170** may control the positions of the wastegates **206** and **208** by controlling the duty cycle (DC) of power applied to the wastegates **206** and **208**.

The exhaust from the left cylinder bank **116** may flow from the wastegates **206** and **208**, through a first exhaust pipe **216**, to a first catalyst **218**. Exhaust pipe surface between the left exhaust manifold **204** and the wastegates **206** and **208** and/or between the wastegates **206** and **208** may also be considered as part of the first exhaust pipe **216**. The first catalyst **218** may include, for example, a diesel oxidation catalyst (DOC), a selective catalyst reductant (SCR) catalyst, a catalytic converter, and/or another suitable type of exhaust catalyst.

The exhaust from the left cylinder bank **116** may flow from the first catalyst **218**, through a second exhaust pipe **220**, to a second catalyst **222**. The second catalyst **222** may include, for example, a DOC, an SCR catalyst, a catalytic converter, and/or another suitable type of exhaust catalyst.

The exhaust from the left cylinder bank **116** may flow from the second catalyst **222**, through a third exhaust pipe **224**, to a third catalyst **226**. The third catalyst **226** may also include, for example, a DOC, an SCR catalyst, a catalytic converter, and/or another suitable type of exhaust catalyst. One or more of the catalysts may be implemented with another component, such as a diesel particulate filter (DPF).

In various implementations, more than one of the first, second, and third catalysts **218**, **222**, and **226** may be combined and implemented as a multi-stage catalyst. For example only, the first and second catalysts **218** and **222** may be implemented as a dual-stage catalyst. In other implementations, the second and third catalysts **222** and **226** may be implemented as a dual-stage catalyst, or the first, second, and third catalysts **218**, **222**, and **226** may all be implemented as a three-stage catalyst.

The exhaust from the left cylinder bank **116** may flow from the third catalyst **226** to a first muffler/tailpipe system **228**. For example only, the first muffler/tailpipe system **228** may include a fourth exhaust pipe **230**, a first muffler **232**, a fifth exhaust pipe **234**, and a first flapper valve **236**. The exhaust may flow from the third catalyst **226**, through the fourth exhaust pipe **230**, to the first muffler **232**.

The first muffler **232** dampens acoustic noise produced by the cylinders **112** of the left cylinder bank **116**. The exhaust may flow from the first muffler **232**, through the fifth exhaust pipe **234**, to the first flapper valve **236**. The first flapper valve **236** may increase pressure within the exhaust system **200**, prevent external objects from entering the exhaust system **200**, and/or perform any other function. The exhaust exits the exhaust system **200** past the first flapper valve **236**.

The exhaust from the cylinders **112** of the right cylinder bank **118** may take a path similar to that of the exhaust from the cylinders **112** of the left cylinder bank **116**, as described above. For example, the exhaust gas expelled from the cylinders **112** of the right cylinder bank **118** may flow from the right exhaust manifold **202** through a third wastegate **250** and a fourth wastegate **252**.

The wastegates **250** and **252** are associated with third and fourth turbochargers **254** and **256**, respectively. The wastegates **250** and **252** and the turbochargers **254** and **256** may be similar or identical to the wastegates **206** and **208** and the turbochargers **210** and **212**, respectively. The ECM **150** (e.g., the actuator control module **170**) may control the wastegates **250** and **252** and, therefore, control the boost of the turbochargers **254** and **256**.

The exhaust from the right cylinder bank **118** may flow from the wastegates **250** and **252**, through a sixth exhaust pipe **258**, to a fourth catalyst **260**. Exhaust pipe surface between the right exhaust manifold **202** and the wastegates **250** and **252** and/or between the wastegates **250** and **252** may also be considered as part of the sixth exhaust pipe **258**. The fourth catalyst **260** may include, for example, a DOC, an SCR catalyst, a catalytic converter, and/or another suitable type of exhaust catalyst.



The exhaust from the right cylinder bank **118** may flow from the fourth catalyst **260**, through a seventh exhaust pipe **262**, to a fifth catalyst **264**. The fifth catalyst **264** may include, for example, a DOC, an SCR catalyst, a catalytic converter, and/or another suitable type of exhaust catalyst

The exhaust from the right cylinder bank **118** may flow from the fifth catalyst **264**, through an eight exhaust pipe **266**, to a sixth catalyst **268**. The sixth catalyst **268** may include, for example, a DOC, an SCR catalyst, a catalytic converter, and/or another suitable type of exhaust catalyst. One or more of the catalysts may be implemented with another component, such as a diesel particulate filter (DPF).

In various implementations, more than one of the fourth, fifth, and sixth catalysts **260**, **264**, and **268** may be combined and implemented as a multi-stage catalyst. For example only, the fourth and fifth catalysts **260** and **264** may be implemented as a dual-stage catalyst. In other implementations, the fifth and sixth catalysts **264** and **268** may be implemented as a dual-stage catalyst, or the fourth, fifth, and sixth catalysts **260**, **264**, and **268** may all be implemented as a three-stage catalyst.

The exhaust from the right cylinder bank **118** may flow from the sixth catalyst **268** to a second muffler/tailpipe system **270**. For example only, the second muffler/tailpipe system **270** may include a ninth exhaust pipe **272**, a second muffler **274**, a tenth exhaust pipe **276**, and a second flapper valve **278**. The exhaust may flow from the sixth catalyst **268**, through the ninth exhaust pipe **272**, to the second muffler **274**.

The second muffler **274** dampens acoustic noise produced by the cylinders **112** of the right cylinder bank **118**. The exhaust may flow from the second muffler **274**, through the tenth exhaust pipe **276**, to the second flapper valve **278**. The second flapper valve **278** may increase pressure within the exhaust system **200**, prevent external objects from entering the exhaust system **200**, and/or perform other functions. The exhaust may exit the exhaust system **200** past the second flapper valve **278**.

One or more exhaust gas recirculation (EGR) systems, such as EGR system **280** may also be implemented. For example only, the EGR system **280** may be associated with the right exhaust manifold **202**, as shown in FIG. **2**. While the EGR system **280** is shown as being connected to the right exhaust manifold **202**, the EGR system **280** may be connected to the exhaust system **200** at another location, such as between the sixth catalyst **268** and the second muffler **274**. The EGR system **280** or another EGR system may be implemented with the components receiving exhaust from the left cylinder bank **116**.

The EGR system **280** includes an EGR valve **282**, a first EGR pipe **284**, a second EGR pipe **286**, an EGR cooler **287**, and a third EGR pipe **288**. The EGR valve **282** is linked to the right exhaust manifold **202** via the first EGR pipe **284**. The EGR valve **282** selectively redirects exhaust gas from the right exhaust manifold **202** back to the intake system via the second EGR pipe **286** and the third EGR pipe **288**. The EGR cooler **287** may be implemented to cool exhaust gas being recirculated back to the intake system. The ECM **150** controls actuation of the EGR valve **282** and, therefore, exhaust gas flowrate (EGF) through the EGR system **280**. For example, the actuator control module **170** may control the opening of the EGR valve **282**.

The ECM **150** includes an exhaust system module **290** that is initially configured based on the exhaust system **200** of FIG. **2**. While the exhaust system module **290** and the actuator control module **170** are shown and discussed as being located within the ECM **150**, the exhaust system module **290** and/or the actuator control module **170** may be located in any suitable location, such as external to the ECM **150**. The exhaust system module **290** receives data that indicates the configuration of an actual exhaust system implemented in the vehicle and re-configures according to the actual exhaust system. The actual exhaust system may include the same components as the exhaust system **200**, or a lesser number of components than the exhaust system **200**.

The exhaust system module **290** estimates (i.e., models) an input gas temperature, an output gas temperature, a mass temperature, and a pressure for each component of the actual exhaust system. The actuator control module **170** selectively adjusts one or more engine operating parameters based on the input gas temperature, output gas temperature, mass temperature, and/or pressure of one or more of the exhaust system components. In this manner, the actuator control module **170** may use the temperatures and/or pressure provided by the exhaust system module **290** to create desired exhaust system conditions.

The configuration module **302** may receive the actual configuration data **320** from any suitable source, such as memory or a device used to calibrate the vehicle.

The exhaust system modeling module **304** models (i.e., determines) one or more pressures and temperatures for each component of the actual exhaust system. More specifically, the exhaust system modeling module **304** models an input temperature, an output temperature, a mass temperature, an input pressure, and an output pressure for each exhaust system component through which exhaust gas flows. The input and output temperatures of a component correspond to the temperature of the exhaust gas input to and output from the component, respectively. The mass temperature corresponds to the temperature of the material(s) that makes up the component itself. The input and output pressures of a component correspond to pressures at an input and at an output of the component, respectively.

The exhaust system modeling module **304** stores the temperatures and pressures for each component of the exhaust system in the storage module **305**. The storage module **305** may be implemented, for example, in memory. An example portion of a table of temperatures and pressures for a portion of the components of the exhaust system **200** that may be stored in the storage module **305** is provided below.

| | Left Manifold | Turbo 1 | Turbo 2 | Pipe 1 | Cat 1 | Pipe 2 | Cat 2 | . . . |
|---|---|---|---|---|---|---|---|---|
| Input Temp | TLM-IN | TT1-IN | TT2-IN | TP1-IN | TC1-IN | TP2-IN | TC2-IN | |
| Mass Temp | TLM-M | TT1-M | TT2-M | TP1-M | TC1-M | TP2-M | TC2-M | |
| Output Temp | TLM-OUT | TT1-OUT | TT2-OUT | TP1-OUT | TC1-OUT | TP2-OUT | TC2-OUT | |
| Input Pressure | PLM-IN | PT1-IN | PT2-IN | PIN-P1 | PIN-C1 | PIN-P2 | PIN-C2 | |
| Output Pressure | PLM-OUT | PT1-OUT | PT2-OUT | POUT-P1 | POUT-C1 | POUT-P2 | POUT-C2 | |

Referring now to FIG. **3**, a functional block diagram of an example implementation of the exhaust system module **290** is presented. The exhaust system module **290** includes a configuration module **302**, an exhaust system modeling module **304**, and a storage module **305**. The exhaust system modeling module **304** includes an exhaust gas flowrate (EGF) determination module **306**, an input temperature module **308**, a steady-state (SS) temperature module **310**, a mass temperature module **312**, an output temperature module **314**, and a pressure determination module **316**.

The exhaust system modeling module **304** is initially configured based on the exhaust system **200** of FIG. **2**. In other words, the exhaust system modeling module **304** is initially configured based on a generic exhaust system that is applicable to a variety of models and types of engine systems and vehicles.

The configuration module **302** receives actual configuration data **320** indicative of an actual exhaust system configuration of the vehicle in which the exhaust system module **290** is implemented. If the actual exhaust system configuration differs from the configuration of the exhaust system **200**, the configuration module **302** re-configures the exhaust system modeling module **304** based on the actual configuration data **320**. Re-configuration may include, for example, enabling and disabling components of the generic configuration based on the actual configuration and/or re-configuring parameters of an enabled component based on the actual configuration.

The EGF determination module **306** determines an EGF for each component of the exhaust system. The EGF of a component corresponds to a mass flowrate of exhaust gas through the component. The EGF determination module **306** may determine the EGF for each of the exhaust system components based on one or more operating parameters. For example only, the EGF for a component may be determined based on the coolant temperature, ethanol concentration of the fuel injected, spark timing, equivalence ratio, vehicle speed, ambient air temperature, intake air temperature, and the accelerator position. The EGF for the component may also be determined based on the EGR flowrate, MAF, air-per-cylinder (APC), ambient air pressure, engine speed, flapper valve position(s), and/or the waste gate duty cycles. The EGF determination module **306** may determine the EGFs, for example, using functions or mappings that relate the operating parameter(s) to the EGFs, respectively.

The EGF determination module **306** may also determine the EGF(s) based on the mode of operation of the engine **102**. For example only, the EGF(s) may be determined based on whether one or more of the cylinders **112** are deactivated, whether the engine **102** is idling, whether the engine **102** is running or shutdown (e.g., hybrid applications), and/or whether the fuel for each firing event is being injected in one or more pulses (e.g., two pulses).

If one or more cylinders are deactivated, the EGF(s) may be determined based on the number of deactivated and/or activated cylinders. The EGF(s) may be determined based on the period of time that the engine **102** has been shutdown (i.e., OFF) when the engine is shutdown. The EGF determination module **306** may also determine the EGF(s) based on various exhaust system modes, such as whether air is being injected into the exhaust system (e.g., by an auxiliary air pump), whether catalyst warmup is occurring, and/or whether light-off is occurring within one or more catalysts of the exhaust system.

The EGF determination module **306** may also determine the EGF(s) based on the actual configuration of the exhaust system and/or characteristics of the various components. For example only, the exhaust system may be configured as to bring together the exhaust gas from the right and left exhaust manifolds **202** and **204** at a confluence point (not shown). The EGF determination module **306** may sum the two EGFs of upstream components for the components downstream of the confluence point. Characteristics that may affect the EGF may include, for example, curvature and/or cross sectional area.

The input temperature module **308** estimates an input temperature for each of the components of the actual exhaust system. The input temperature of a component corresponds to the temperature of exhaust gas at an input of that component. The input temperature module **308** stores the input temperatures for the components, respectively, in the storage module **305**. The input temperature module **308** may set the input temperature for a component equal to or based on the output temperature of the preceding (i.e., upstream) component of the exhaust system. For example only, the input temperature module **308** may set the input temperature for an N-th component of the exhaust system based on the output temperature of an (N−1)-th component.

For an exhaust manifold (e.g., the right and left exhaust manifolds **202** and **204**) the input temperature module **308** may set the input temperatures equal to or based on an engine output temperature. The input temperature module **308** may determine the engine output temperature based on one or more operating parameters, such as the engine load, the APC, the engine speed, the spark timing, the equivalence ratio, the ethanol concentration of the fuel, the vehicle speed, and/or the warmup state of the engine **102**. The input temperature module **308** may determine the engine output temperature using a function or mapping that relates the operating parameters to the engine output temperature.

When the exhaust system includes an EGR system (e.g., the EGR system **280**), the input temperature module **308** determines an input temperature for the EGR system based on a temperature of the exhaust gas at the point where the EGR system connects to the exhaust system. The input temperature module **308** may also determine input temperature for each component of the EGR system, such as the EGR pipes, the EGR valve, and/or the EGR cooler.

The SS temperature module **310** estimates an SS temperature for each component of the actual exhaust system. The SS temperature for a component corresponds to a temperature that the component itself will reach if the engine load conditions remain constant (i.e., steady state). The SS temperature module **310** determines the SS temperature for the component based on the input temperature of the component, the ambient temperature, and a SS coefficient determined for the component.

The SS temperature module **310** determines the SS coefficient for the component based on the EGF for the component. For example only, the SS temperature module **310** may determine the SS temperature for the component using the equation:

$$T_{SS}=(T_{IN}-T_A)*C_{SS},$$

where $T_{SS}$ is the SS temperature of the component, $T_{IN}$ is the input temperature of the component, $T_A$ is the ambient air temperature, and $C_{SS}$ is the SS coefficient for the component.

The SS temperature module **310** determines the SS coefficient for a turbocharger (e.g., the turbochargers **210**, **212**, **254**, and/or **256**) based on the EGF for the turbochargers and the DC of power applied to the associated wastegate. For example only, the SS temperature module **310** may determine the SS coefficient for the turbocharger **212** based on the EGF for the turbocharger **212** and the DC of power applied to the wastegate **206**.

As the turbocharger draws in ambient air, the SS temperature module **310** also adjusts the SS temperature for the turbocharger based on the intake air temperature. For example only, the SS temperature module **310** may determine the SS temperature for the turbocharger using the equation:

$$T_{SS\text{-}T}=IAT+C_{SS\text{-}T}*(T_{IN\text{-}T}-IAT),$$

where $T_{SS\text{-}T}$ is the SS temperature of the turbocharger, IAT is the intake air temperature, $C_{SS\text{-}T}$ is the SS coefficient for the turbocharger, and $T_{IN\text{-}T}$ is the input temperature for the turbocharger.

The mass temperature module **312** determines a mass temperature for each of the exhaust system components. The mass temperature module **312** stores the mass temperatures in the storage module **305**. The mass temperature module **312** determines the mass temperature for a component based on the SS temperature of the component and a mass coefficient determined for the component. The mass temperature corresponds to the temperature of the material that makes up the component.

The mass temperature module **312** determines the mass coefficient for the component based on the EGF determined for the component. The mass coefficient corresponds to the rate at which the mass temperature is changing toward the SS temperature of the component. For example only, the mass coefficient may increase as the EGF decreases. The mass temperature module **312** determines the mass temperature for the component based on, for example, a product of the SS temperature and the mass coefficient.

The mass temperature module **312** determines the mass coefficient for a turbocharger (e.g., the turbochargers **210**, **212**, **254**, and/or **256**) based on the EGF for the turbochargers and the DC of power applied to the associated wastegate. For example only, the mass temperature module **312** may determine the mass coefficient for the turbocharger **212** based on the EGF for the turbocharger **212** and the DC of power applied to the wastegate **206**.

The output temperature module **314** determines an output temperature for each of the exhaust system components. The output temperature of a component corresponds to the temperature of exhaust gas at an output of that component. The output temperature module **314** stores the output temperatures in the storage module **305**.

The output temperature module **314** may determine the output temperature for a component based on the input temperature for the component, the mass temperature of the component, and an output coefficient for the component. The output temperature module **314** determines the output temperature for the component based in the input temperature of the component plus or minus the change in temperature attributable to heat transfer between the component and air passing the component. More specifically, the output temperature module **314** determines the output temperature by adjusting the input temperature toward the mass temperature based on the output coefficient.

The output temperature module **314** determines the output coefficient for the component based on the EGF of the component. For example only, the output temperature module **314** may determine the output temperature for the component using the equation:

$$T_{OUT}=T_{IN}+(T_{IN}-T_{MASS})*C_{OUT},$$

where $T_{OUT}$ is the output temperature of the component, $T_{IN}$ is the input temperature of the component, $T_{MASS}$ is the mass temperature of the component, and $C_{OUT}$ is the output coefficient of the component.

Catalysts of the exhaust system, such as the catalysts **218**, **222**, **226**, **260**, **264**, and **268** may also produce heat. Accordingly, the output temperature module **314** increases the output temperature of a catalyst of the exhaust system based on the heat generated by the catalyst. The SS temperature module **310** and the mass temperature module **312** may also increase the SS temperature and the mass temperature of the catalyst, respectively, based on the heat generated by the catalyst.

The amount of heat generated by the catalyst will be referred to as a heat generation term. The heat generation term for the catalyst may be determined based on the EGF of the catalyst, the equivalence ratio, and/or the ethanol concentration of the fuel. For example only, when the equivalence ratio is 1.0 (i.e., when a stoichiometric air/fuel mixture being combusted), the heat generation term may be negligible. The heat generation term for the catalyst may also be determined based on whether an air is being supplied into the whether air is being injected into the exhaust system (e.g., by an auxiliary air pump) and/or whether the fuel for each firing event is being injected in one or more pulses (e.g., two pulses).

The output temperature module **314** determines the output coefficient for a turbocharger (e.g., the turbochargers **210**, **212**, **254**, and/or **256**) based on the EGF for the turbochargers and the DC of power applied to the associated wastegate. The output temperature module **314** determines the output coefficient for the turbocharger **212** based on the EGF for the turbocharger **212** and the DC of power applied to the wastegate **206**. For example only, the output temperature module **314** may determine the output temperature for the turbocharger using the equation:

$$T_{OUT\text{-}T}=T_{IN\text{-}T}+C_{OUT\text{-}T}*(T_{M\text{-}T}-T_{IN\text{-}T})$$

where $T_{OUT\text{-}T}$ is the output temperature of the turbocharger, $T_{IN\text{-}T}$ is the input temperature for the turbocharger, $C_{OUT\text{-}T}$ is the output coefficient for the turbocharger, and $T_{M\text{-}T}$ is the mass temperature for the turbocharger.

The pressure determination module **316** determines an input pressure, an output pressure, and a pressure drop for each of the exhaust system components. The input pressure of a component corresponds to the pressure at the input of that component. The output pressure of a component corresponds to the pressure at the output of that component. The pressure drop of a component corresponds to the pressure decrease present between the input pressure of the component and the output pressure of the component. The pressure determination module **316** stores the input pressures and the output pressures in the storage module **305**. The pressure determination module **316** may also store the pressure drops in the storage module **305**.

FIG. **4** includes a functional block diagram of an example implementation of the pressure determination module **316**. The pressure determination module **316** begins with the last component in the actual exhaust system. The last component is the last component that exhaust flows through before exiting the exhaust system to the atmosphere. Dual output exhaust systems include two last components.

The pressure determination module **316** sets the output pressure for the last component equal to or based on ambient (barometric) air pressure. The pressure determination module **316** determines the pressure drop for the last component, as discussed further below. The pressure determination module **316** determines the input pressure for the last component based on the output pressure of the last component and the pressure drop of the last component.

For the next component upstream of the last component (moving toward an exhaust manifold), the pressure determination module **316** sets the output pressure for that component based on or equal to the input pressure of the last component. The pressure determination module **316** determines the pressure drop for the next component, and determines the input pressure for the next component based on the output pressure of the next component and the pressure drop of the next component. This process continues for each component working upstream until the exhaust manifold is reached. An example of how to determine the pressure drop for a component and the input pressure for a component will now be discussed.

Referring now to FIG. **4**, a specific gas constant module **404** determines a specific gas constant **408** for the exhaust gas in the actual exhaust system. The specific gas constant **408** may be used for each component of the actual exhaust system as the amount of variation from component to component may be negligible.

The specific gas constant module **404** determines the specific gas constant **408** based on an equivalence ratio (EQR) **412** of the air/fuel mixture being combusted within the engine **102**, a stoichiometric fuel to air ratio (FAR), and a humidity **416** of ambient air. The humidity **416** may be measured, for example, using a humidity sensor or determined based on one or more other parameters, such as the IAT. The specific gas constant module **404** may determine the specific gas constant **408**, for example, using a function or a mapping (e.g., a lookup table) that relates EQRs, stoichiometric FARs, and ambient humidities to specific gas constants. An example function for determining the specific gas constant **408** for a gasoline and/or ethanol fueled engine is:

$$R_S=\frac{337.9*Stoich*EQR+1.744*H-17.5*EQR+286.8}{1+Stoich*EQR},$$

where $R_S$ is the specific gas constant **408**, Stoich is the stoichiometric FAR, EQR is the EQR **412** of the air/fuel mixture being combusted within the engine **102**, and H is the ambient humidity **416**. Other functions may be used for other types of fueling.

A viscosity module **420** determines a viscosity **424** of the exhaust gas within the component and a normalized viscosity **428** of the exhaust gas within the component. The viscosity **424** and the normalized viscosity **428** may be determined specifically for each different component of the actual exhaust system.

The viscosity module **420** determines the viscosity **424** for the component based on the input temperature **432** determined for the component (by the input temperature module **308**). The viscosity module **420** may obtain the input temperature **432** from the storage module **305**. In the case of a catalyst, due to the catalyst generating heat, a temperature of the catalyst (e.g., the mass temperature of the catalyst) may be used in place of the input temperature of the catalyst.

The viscosity module **420** may determine the viscosity **424** for the component, for example, using a function or a mapping that relates input temperatures of the component to viscosities. An example function for determining the viscosity **424** is:

$$\mu = \frac{(T_{IN} + 273)^{1.5}}{664010 * (T_{IN} + 461)},$$

where μ is the viscosity **424** (e.g., in kg/m*s), and $T_{IN}$ is the input temperature **432** of the component (e.g., in degrees Celsius). In the case of a mapping, the mapping is calibrated with entries for values of the viscosity **424** at various input temperatures.

As the function or mapping may be calibrated under different operating conditions, the viscosity module **420** determines the normalized viscosity **428** based on a normalization temperature where the function or mapping was calibrated. The viscosity module **420** may determine whether to use a first relationship or mapping or to use a second relationship or mapping based on whether the normalization temperature is greater than a predetermined temperature. For example, when the normalization temperature is greater than the predetermined temperature, the viscosity module **420** may determine the normalized viscosity **428** using the first relationship or mapping, which is the same as that used to determine the viscosity **424**.

When the normalization temperature is less than the predetermined temperature, the viscosity module **420** may determine the normalized viscosity **428** using the second relationship or mapping. The predetermined temperature may be calibrated and may be, for example, approximately 40 degrees Celsius or another suitable temperature. An example of the second function for determining the normalized viscosity **428** is:

$$\mu_N = \frac{(T_{IN} + 273)^{1.5}}{661358 * (T_{IN} + 393)},$$

where $\mu_N$ is the normalized viscosity **428** (e.g., in kg/m*s) and $T_{IN}$ is the input temperature **432** of the component. In the case of a second mapping, the second mapping is calibrated with entries for values of the normalized viscosity **428** at various input temperatures while at the normalized temperature. The normalization temperature may be a predetermined value stored in memory. Along with the normalization temperature, predetermined values of an associated normalization specific gas constant ($R_N$) and an associated normalization exhaust density ($\rho_{U,N}$) are also stored for normalizing other parameters.

A density module **436** determines a density **440** of the exhaust gas within the component and a normalized density **444** of the exhaust gas within the component. The density **440** and the normalized density **444** may be determined specifically for each different component of the actual exhaust system.

The density module **436** determines the viscosity **424** for the component based on the input temperature **432** determined for the component (by the input temperature module **308**) and a last input pressure **448** determined for the component. The temperatures and the pressures for each component may be determined at a predetermined rate, such as every 12.5 milliseconds or another suitable rate. The last input pressure **448** determined for the component therefore corresponds to the input pressure determined for the component the last time that the pressures and temperatures were determined. The density module **436** may obtain the input temperature **432** and the last input pressure **448** from the storage module **305**. As stated above, in the case of a catalyst, due to the catalyst generating heat, the temperature of the catalyst (e.g., the mass temperature of the catalyst) may be used in place of the input temperature of the catalyst.

The density module **436** may determine the density **440** for the component, for example, using a function or a mapping that relates input temperatures and input pressures of the component to densities. An example function for determining the density **440** is:

$$\rho = \frac{1000 * P_{IN-L}}{R_S * (T_{IN} + 273.15)},$$

where ρ is the density **440** (e.g., in kg/m$^3$), $T_{IN}$ is the input temperature **432** of the component (e.g., in degrees Celsius), and $p_{IN-L}$ is the last input pressure **448** of the component (e.g., in kPa). In the case of a mapping, the mapping is calibrated with entries for values of the density **440** at various input temperatures and last input pressures.

Because the function or mapping may be calibrated under different operating conditions, the density module **436** determines the normalized density **444** based on the normalization temperature, a normalized upstream pressure for the component, and the normalization specific gas constant ($R_N$). An example function for determining the normalized density **444** is:

$$\rho_N = \frac{1000 * P_{IN-N}}{R_{SN} * (T_N + 273.15)},$$

where $\rho_N$ is the normalized density **444** (e.g., in kg/m$^3$), $T_N$ is the predetermined normalization temperature, and $p_{IN-N}$ is the normalized input pressure for the component (e.g., in kPa).

The density module **436** determines the normalized input pressure for the component ($p_{IN-N}$) based on a normalized ambient air pressure for the component, ambient air pressure **452**, the last input pressure **448** of the component, and a pressure normalization value **456** for the component. The density module **436** may determine the normalized input pressure for the component, for example, using a function or mapping. An example function for determining the normalized input pressure is:

$$p_{IN-N} = p_{amb,n} + (p_{IN-L} - p_{AMB}) * f_P,$$

where $P_{IN-N}$ is the normalized input pressure for the component, $P_{amb,n}$ is the normalized ambient air pressure for the component, $P_{IN-L}$ is the last input pressure for the component, $P_{AMB}$ is the ambient air pressure **452**, and $f_P$ is the pressure normalization value **456** for the component. The normalized ambient air pressure may be a predetermined value for the component that is stored in memory. A normalized ambient air pressure may be stored for each different component of the actual exhaust system. The ambient air pressure **452** may be measured using a sensor or determined based on one or more other parameters.

A first normalization value module **460** determines the pressure normalization value **456**. When the engine **102** is started, the first normalization value module **460** may initialize the pressure normalization value **456** to a predetermined initialization value, such as 1.0. After initialization, the first normalization value module **460** determines the pressure normalization value **456** based on the last value of the viscosity **424**, the last value of the normalized viscosity **428**, the last value of the density **440**, and the last value of the normalized density **444**. The first normalization value module **460** may determine the pressure normalization value **456**, for example, using a function or a mapping. An example of a function for determining the pressure normalization value **456** is:

$$f_P = \frac{\rho}{\rho_N}\left(\frac{\mu_N}{\mu}\right)^2,$$

where $f_P$ is the pressure normalization value **456**, $\mu$ is the last value of the viscosity **424**, $\mu_N$ is the last value of the normalized viscosity **428**, $\rho$ is the last value of the density **440**, and $\rho_N$ is the last value of the normalized density **444**.

An EGF normalization module **464** determines a normalized EGF **468** for the component based on the EGF **472** determined for the component (by the EGF determination module **306**) and a flow normalization value **476**. The EGF normalization module **464** may obtain the EGF **472** from the storage module **305**. The EGF normalization module **464** may determine the normalized EGF **468**, for example, using a function or a mapping. An example of a function for determining the normalized EGF **468** is:

$$EGF_N = EGF * f_M,$$

where $EGF_N$ is the normalized EGF **468**, EGF is the EGF **472** determined for the component, and $f_M$ is the flow normalization value **476**.

A second normalization value module **480** determines the flow normalization value **476**. When the engine **102** is started, the second normalization value module **480** may initialize the flow normalization value **476** to a predetermined initialization value, such as 1.0. After initialization, the second normalization value module **480** determines the flow normalization value **476** based on the last value of the viscosity **424** and the last value of the normalized viscosity **428**. The second normalization value module **480** may determine the flow normalization value **476**, for example, using a function or a mapping. An example of a function for determining the flow normalization value **476** is:

$$f_M = \frac{\mu_N}{\mu},$$

where $f_M$ is the flow normalization value **476**, $\mu$ is the last value of the viscosity **424**, and $\mu_N$ is the last value of the normalized viscosity **428**.

A pressure drop module **484** determines a pressure drop **488** for the component based on a normalized pressure drop of the component and the pressure normalization value **456**. The pressure drop module **484** may determine the pressure drop **488**, for example, using a function or a mapping that relates normalized pressure drops and pressure normalization values to pressure drops. An example function for determining the pressure drop **488** is:

$$PDrop = \frac{PDrop_N}{f_P},$$

where PDrop is the pressure drop **488**, $PDrop_N$ is the normalized pressure drop of the component, and $f_P$ is the pressure normalization value **456**. The pressure drop module **484** determines the normalized pressure drop of the component based on the normalized EGF **468** of the component. For example, the pressure drop module **484** may determine the normalized pressure drop of the component using a function or a mapping that relates normalized EGFs to normalized pressure drops.

An input pressure module **492** determines the input pressure **496** for the component based on the pressure drop **488** of the component and the output pressure **498** determined for the component. An output pressure module **497** sets the output pressure **498** of a component equal to or based on the input pressure of a next component immediately downstream of that component. For the last component of the actual exhaust system, the output pressure module **497** sets the output pressure **498** equal to or based on the ambient air pressure **452**. The output pressure module **497** obtains the input pressures from the storage module **305** and stores the output pressures of the components in the storage module **305**.

The input pressure module **492** determines the input pressure **496** by adding the pressure drop **488** to the output pressure **498**. The input pressure module **492** stores the input pressure **496** in the storage module **305** in association with the component. This process continues for each component in the actual exhaust system working upstream towards the exhaust manifold(s).

The actuator control module **170** selectively adjusts one or more engine operating parameters based on the parameters stored in the storage module **305**. More specifically, the actuator control module **170** selectively adjusts one or more engine parameters based on the temperatures and/or pressures of one or more of the components of the actual exhaust system. For example only, the actuator control module **170** may adjust the amount of fuel injected, airflow into the engine **102**, and/or the spark timing based on one or more of the pressures and temperatures stored in the storage module **305**.

Referring now to FIG. **5**, a flowchart depicting an example method of determining the input pressure for the components of the actual exhaust system is presented. Control begins with **550** where control initializes. For example only, the configuration module **302** may reset previously stored values and/or configure the exhaust system modeling module **304** at **550**. The configuration module **302** configures the exhaust system modeling module **304** based on the actual exhaust system configuration of the vehicle.

The configuration module **302** may also reset a counter value (an N value) to a predetermined reset value (an M value) at **550**. The predetermined reset value may be set to, for example only, the total number of components of the exhaust system. In this manner, control begins at the last component of the exhaust system, such as a muffler/tailpipe system.

The pressure determination module **316** determines whether the counter value is less than 1 at **554**. If **554** is true, control the pressure determination module **316** resets the counter value to the predetermined reset value at **558**. In this manner, the pressure determination module **316** resets the counter value to the total number of components of the actual exhaust system. If **554** is false, control continues with **562**. The pressure determination module **316** decrements the counter value at **562**, and control continues with **566**. While resetting the counter value (N value) to the predetermined reset value (M value) and decrementing the counter value are provided as an example, resetting the counter value to zero, incrementing the counter value, and comparing the counter value with the total number of components in the actual exhaust system may be used.

At **566**, the pressure determination module **316** sets the output pressure for the N-th component of the actual exhaust system to the input pressure for the N+1-th component of the actual exhaust system. In the case of the last component of the actual exhaust system (i.e., when N=M), the pressure determination module **316** sets the output pressure equal to or based on the ambient air pressure **452**.

At **570**, the viscosity module **420** determines the viscosity **424** of the exhaust gas input to the N-th component and determines the normalized viscosity **428** of the exhaust gas input to the N-th component. The specific gas constant module **404** determines the specific gas constant **408** at **574**. As stated above, the specific gas constant **408** may be used for each component of the actual exhaust system. The specific gas constant **408** may therefore be determined at a different time, such as at **558**.

The first normalization value module **460** determines the pressure normalization value **456** at **578**. The second normalization value module **480** also determines the flow normalization value **476** at **578**. At **582**, the density module **436** determines the density **440** of the exhaust gas input to the N-th component and determines the normalized density **444** of the exhaust gas input to the N-th component. As discussed above, the density module **436** determines the density **440** and the normalized density **444** based on the temperature of exhaust gas input to the N-th component.

At **586**, the EGF normalization module **464** obtains the EGF **472** for the N-th component from the storage module **305**. The EGF normalization module **464** determines the normalized EGF **468** for the N-th component at **586**. The pressure drop module **484** determines the normalized pressure drop for the N-th component of the actual exhaust system at **588**. At **590**, the pressure drop module **484** determines the pressure drop **488** for the N-th component of the actual exhaust system.

The input pressure module **492** determines the input pressure **496** for the N-th component of the actual exhaust system at **594** based on the output pressure of the N-th component and the pressure drop **488** across the N-th component. The input pressure module **492** stores the input pressure **496** in the storage module **305** in association with the N-th component. Control then returns to **554** to continue with for a next component upstream of the N-th component (i.e., the N−1-th component). Thus, the process is iterative in nature. The actuator control module **170** may control one or more operating parameters based on one or more of the parameters stored in the storage module **305**.

The foregoing description is merely illustrative in nature and is in no way intended to limit the disclosure, its application, or uses. The broad teachings of the disclosure can be implemented in a variety of forms. Therefore, while this disclosure includes particular examples, the true scope of the disclosure should not be so limited since other modifications will become apparent upon a study of the drawings, the specification, and the following claims. As used herein, the phrase at least one of A, B, and C should be construed to mean a logical (A OR B OR C), using a non-exclusive logical OR, and should not be construed to mean "at least one of A, at least one of B, and at least one of C." It should be understood that one or more steps within a method may be executed in different order (or concurrently) without altering the principles of the present disclosure.

In this application, including the definitions below, the term 'module' or the term 'controller' may be replaced with the term 'circuit' The term 'module' may refer to, be part of, or include: an Application Specific Integrated Circuit (ASIC); a digital, analog, or mixed analog/digital discrete circuit; a digital, analog, or mixed analog/digital integrated circuit; a combinational logic circuit; a field programmable gate array (FPGA); a processor circuit (shared, dedicated, or group) that executes code; a memory circuit (shared, dedicated, or group) that stores code executed by the processor circuit; other suitable hardware components that provide the described functionality; or a combination of some or all of the above, such as in a system-on-chip.

The module may include one or more interface circuits. In some examples, the interface circuits may include wired or wireless interfaces that are connected to a local area network (LAN), the Internet, a wide area network (WAN), or combinations thereof. The functionality of any given module of the present disclosure may be distributed among multiple modules that are connected via interface circuits. For example, multiple modules may allow load balancing. In a further example, a server (also known as remote, or cloud) module may accomplish some functionality on behalf of a client module.

The term code, as used above, may include software, firmware, and/or microcode, and may refer to programs, routines, functions, classes, data structures, and/or objects. The term shared processor circuit encompasses a single processor circuit that executes some or all code from multiple modules. The term group processor circuit encompasses a processor circuit that, in combination with additional processor circuits, executes some or all code from one or more modules. References to multiple processor circuits encompass multiple processor circuits on discrete dies, multiple processor circuits on a single die, multiple cores of a single processor circuit, multiple threads of a single processor circuit, or a combination of the above. The term shared memory circuit encompasses a single memory circuit that stores some or all code from multiple modules. The term group memory circuit encompasses a memory circuit that, in combination with additional memories, stores some or all code from one or more modules.

The term memory circuit is a subset of the term computer-readable medium. The term computer-readable medium, as used herein, does not encompass transitory electrical or electromagnetic signals propagating through a medium (such as on a carrier wave); the term computer-readable medium may therefore be considered tangible and non-transitory. Non-limiting examples of a non-transitory, tangible computer-readable medium are nonvolatile memory circuits (such as a flash memory circuit, an erasable programmable read-only memory circuit, or a mask read-only memory circuit), volatile memory circuits (such as a static random access memory circuit or a dynamic random access memory circuit), magnetic storage media (such as an analog or digital magnetic tape or a hard disk drive), and optical storage media (such as a CD, a DVD, or a Blu-ray Disc).

The apparatuses and methods described in this application may be partially or fully implemented by a special purpose computer created by configuring a general purpose computer to execute one or more particular functions embodied in computer programs. The functional blocks and flowchart elements described above serve as software specifications, which can be translated into the computer programs by the routine work of a skilled technician or programmer.

The computer programs include processor-executable instructions that are stored on at least one non-transitory, tangible computer-readable medium. The computer programs may also include or rely on stored data. The computer programs may encompass a basic input/output system (BIOS) that interacts with hardware of the special purpose computer, device drivers that interact with particular devices of the special purpose computer, one or more operating systems, user applications, background services, background applications, etc.

The computer programs may include: (i) descriptive text to be parsed, such as HTML (hypertext markup language) or XML (extensible markup language), (ii) assembly code, (iii) object code generated from source code by a compiler, (iv) source code for execution by an interpreter, (v) source code for compilation and execution by a just-in-time compiler, etc. As examples only, source code may be written using syntax from languages including C, C++, C#, Objective C, Haskell, Go, SQL, R, Lisp, Java®, Fortran, Perl, Pascal, Curl, OCaml, Javascript®, HTML5, Ada, ASP (active server pages), PHP, Scala, Eiffel, Smalltalk, Erlang, Ruby, Flash®, Visual Basic®, Lua, and Python®.

None of the elements recited in the claims are intended to be a means-plus-function element within the meaning of 35 U.S.C. §112(f) unless an element is expressly recited using the phrase "means for," or in the case of a method claim using the phrases "operation for" or "step for."

What is claimed is:

**1**. A pressure determination system for a vehicle, comprising:

an output pressure module that sets an output pressure of a first component of an exhaust system of the vehicle equal to one of:

an input pressure of a second component that is immediately downstream of the first component in the exhaust system; and

ambient air pressure;

a pressure drop module that determines a pressure drop between an input of the first component and an output of the first component based a temperature of exhaust input to the first component;

an input pressure module that determines an input pressure of the first component based on a sum of the output pressure of the first component and the pressure drop between the input and the output of the first component; and

an actuator control module that selectively controls at least one engine actuator based on at least one of the input and output pressures of the first component.

**2**. The pressure determination system of claim **1** wherein:

the output pressure module further sets an output pressure of a third component of the exhaust system that is immediately upstream of the first component in the exhaust system equal to the input pressure of the first component;

the pressure drop module further determines a pressure drop between an input of the third component and an output of the third component based a temperature of exhaust input to the third component; and

the input pressure module further determines an input pressure of the third component based on a sum of the output pressure of the third component and the pressure drop between the input and the output of the third component.

**3**. The pressure determination system of claim **1** further comprising:

a viscosity module that determines a viscosity of the exhaust input to the first component based on the temperature of the exhaust input to the first component; and

a density module that determines a density of the exhaust input to the first component based on the temperature of the exhaust input to the first component,

wherein the pressure drop module determines the pressure drop between the input and the output of the first component based on the viscosity and the density of the exhaust input to the first component.



**4**. The pressure determination system of claim **3** further comprising:

an exhaust gas flowrate (EGF) determination module that determines an EGF through the first component; and

an EGF normalization module that determines a normalized EGF through the first component based on the EGF and the viscosity of the exhaust input to the first component,

wherein the pressure drop module determines the pressure drop between the input and the output of the first component based on the normalized EGF.

**5**. The pressure determination system of claim **4** further comprising:

a first normalization value module that determines a first normalization value for the first component based on the viscosity of the exhaust input to the first component and the density of the exhaust input to the first component,

wherein the pressure drop module further determines a normalized pressure drop between the input and the output of the first component based on the normalized EGF through the first component and determines the pressure drop between the input and the output of the first component based on the normalized pressure drop and the first normalization value.

**6**. The pressure determination system of claim **5** wherein the pressure drop module determines the pressure drop between the input and the output of the first component based on the normalized pressure drop divided by the first normalization value.

**7**. The pressure determination system of claim **5** wherein the first normalization value module determines the first normalization value for the first component based on the viscosity of the exhaust input to the first component, a normalized viscosity of the exhaust input to the first component, the density of the exhaust input to the first component, and a normalized density of the exhaust input to the first component.

**8**. The pressure determination system of claim **5** wherein the density module determines the density of the exhaust input to the first component further based on a normalized input pressure for the first component and determines the normalized input pressure for the first component based on a normalized ambient air pressure, a previous value of the input pressure of the first component, an ambient air pressure, and the first normalization value.

**9**. The pressure determination system of claim **4** further comprising:

a second normalization value module that determines a second normalization value for the first component based on the viscosity of the exhaust input to the first component,

wherein the EGF normalization module determines the normalized EGF through the first component based on the EGF through the first component and the second normalization value.

**10**. The pressure determination system of claim **9** wherein the second normalization value module determines the second normalization value for the first component based on the viscosity of the exhaust input to the first component and a normalized viscosity of the exhaust input to the first component.

**11**. A method for a vehicle, comprising:

setting an output pressure of a first component of an exhaust system of the vehicle equal to one of:

an input pressure of a second component that is immediately downstream of the first component in the exhaust system; and

ambient air pressure;

determining a pressure drop between an input of the first component and an output of the first component based a temperature of exhaust input to the first component;

determining an input pressure of the first component based on a sum of the output pressure of the first component and the pressure drop between the input and the output of the first component; and

selectively controlling at least one engine actuator based on at least one of the input and output pressures of the first component.

**12**. The method of claim **11** further comprising:

setting an output pressure of a third component of the exhaust system that is immediately upstream of the first component in the exhaust system equal to the input pressure of the first component;

determining a pressure drop between an input of the third component and an output of the third component based a temperature of exhaust input to the third component; and

determining an input pressure of the third component based on a sum of the output pressure of the third component and the pressure drop between the input and the output of the third component.

**13**. The method of claim **11** further comprising:

determining a viscosity of the exhaust input to the first component based on the temperature of the exhaust input to the first component;

determining a density of the exhaust input to the first component based on the temperature of the exhaust input to the first component; and

determining the pressure drop between the input and the output of the first component based on the viscosity and the density of the exhaust input to the first component.

**14**. The method of claim **13** further comprising:

determining an exhaust gas flowrate (EGF) through the first component;

determining a normalized EGF through the first component based on the EGF and the viscosity of the exhaust input to the first component; and

determining the pressure drop between the input and the output of the first component based on the normalized EGF.

**15**. The method of claim **14** further comprising:

determining a first normalization value for the first component based on the viscosity of the exhaust input to the first component and the density of the exhaust input to the first component;

determining a normalized pressure drop between the input and the output of the first component based on the normalized EGF through the first component; and

determining the pressure drop between the input and the output of the first component based on the normalized pressure drop and the first normalization value.

**16**. The method of claim **15** further comprising determining the pressure drop between the input and the output of the first component based on the normalized pressure drop divided by the first normalization value.

**17**. The method of claim **15** further comprising determining the first normalization value for the first component based on the viscosity of the exhaust input to the first component, a normalized viscosity of the exhaust input to the first component, the density of the exhaust input to the first component, and a normalized density of the exhaust input to the first component.

**18**. The method of claim **15** further comprising:

determining the density of the exhaust input to the first component further based on a normalized input pressure for the first component; and

determining the normalized input pressure for the first component based on a normalized ambient air pressure, a previous value of the input pressure of the first component, an ambient air pressure, and the first normalization value.

**19**. The method of claim **14** further comprising:

determining a second normalization value for the first component based on the viscosity of the exhaust input to the first component; and

determining the normalized EGF through the first component based on the EGF through the first component and the second normalization value.

**20**. The method of claim **19** further comprising determining the second normalization value for the first component based on the viscosity of the exhaust input to the first component and a normalized viscosity of the exhaust input to the first component.

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